



Research article

Optimization model of crop planning considering crop rotation with adjacency plots and nutrient cycling

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Article Info

Article history:

Received 15 January 2022

Revised 6 June 2023

Accepted 2 July 2023

Available online 31 August 2023

Keywords:

Adjacency plot,
Agricultural production planning,
Crop rotation,
Nutrient cycling,
Optimization

Abstract

Importance of the work: Application of the organic farming system is intended to support soil quality without any long-term disruption. Several concepts were developed to support the goals of organic farming, such as crop rotation, adjacency plots and soil quality.

Objectives: To formulate a planning model by implementing a crop rotation system considering adjacency plots and nutrient cycling.

Materials & Methods: Mixed integer linear programming was used to develop the model whose objective was to maximize the profit by seeking the best options for what, when and where to plant crops following economic limitations. Crop rotation was used to solve the yield-shifting problem for sustainable agriculture.

Results: The model solved the crop planning problem based on the pull supply chain and maximized land utilization despite expressing the demand in terms of maximizing the profit. The proposed crop planning model proposed the crop planting sequence within organic farming principles. In addition, the model determined the optimum amount of additional nutrients needed within the planning horizon to satisfy the demand. The model tended to increase productivity rather than utilizing another plot to satisfy the demand. The experiment showed that the full allocation condition resulted in higher plot utilization with a profit difference of approximately USD 13,000/planting period.

Main finding: The developed optimization model for crop planning could be used as a decision-making tool by farmers to optimize profit and productivity. The experimental results showed that by using the full-allocation scenario, farmers would achieve higher profits and plot utilization.

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<https://doi.org/10.34044/j.anres.2023.57.4.02>

Introduction

Agriculture is one of the vital sectors for the sustainability of human life and its development is also part of many countries' integrated efforts to improve their competitiveness and maximize that sector's contribution to the country's economy (Director General of Horticulture, 2019). However, agricultural products from developing countries are not always competitive, even domestically. This problem is caused by less-than-optimal land productivity. Furthermore, most farmers use synthetic fertilizers and pesticides, which cause a decrease in the content of organic matter in the soil, with these chemical elements resulting in poor crop yields in the long run. Therefore, it is essential to improve production management in the agricultural industry to maximize the sustainable profitability of the farmers.

Farmer requires production planning as a guide in cultivating their farms. Production planning in the agricultural sector includes scheduling the types of crops that will be planted, when the planting process will be undertaken and where the crops will be planted. However, there are numerous challenges in conducting production planning in the agricultural industry, with some obstacles involve a lack of natural resources and limited agricultural land (Despoudi et al., 2018).

There are several factors need to be considered in crop planning decisions, such as water irrigation management (Zhang et al., 2018), the amount and variability of spoilage risk (Villa et al., 2019), climate and crop prices (Jahel et al., 2018; Randall et al., 2022) and crop sequences with temporal and spatial variations (Fikry et al., 2021). The current research focused on three concepts of production planning that are commonly used in organic farming systems: crop rotation, adjacency plots and soil quality.

Crop rotation is defined as the sequential production of different plant species on the same plot (Karlen and Sharpley, 1994). Crop rotation refers to the process of determining what crops to plant in each cycle. The objectives of crop rotation are to ensure food security (Makarim, 2015), reduce losses due to crop diversity (Urbano and Moro, 1992), improve the quality of the soil structure (Triberti et al., 2016), avoid the risk of pest and disease attacks (Food and Agriculture Organization of the United Nations, 2021) and increase the population of beneficial microorganisms in the soil (Prihastuti, 2011).

Adjacency plots are a guideline for organic farming systems that regulate the location of adjacency plants (Tan and Nihan, 2012). Adjacency plots will increase the effectiveness

of crop rotation by considering adjacency between plots and can reduce the risk of pest attacks that spread through water, soil and air.

Soil quality is related to soil fertility; good soil quality will support productivity growth, while a decrease in soil fertility can cause a decrease in crop yield. In organic farming systems, nutrient sources to overcome the loss of nitrogen, phosphorus and potassium from a site must come from organic sources or organic fertilizer. Organic fertilizers are derived from animal matter, human excreta or vegetable matter, such as compost and manure (Assefa and Tadesse, 2019).

Several research models have been investigated regarding the development of a sustainable planning model. dos Santo et al. (2011) discussed the development of a sustainable crop rotation planning model by providing ecological limitations, illustrated by the limitation that a crop within one family cannot be planted in rotation and cannot be planted on adjacent plots of land. This model aims to maximize land use to achieve the objective of maximizing revenue.

The current study aimed to determine a planning model by implementing a crop rotation system considering adjacency plots and nutrient cycles based on mixed integer linear programming (MILP), using profit as a benchmark to determining the best agricultural production planning option. Thus, the purpose of the developed model was to maximize profits. The model developed in this research could be used annually for crop planning in agriculture production businesses to know what, when and where to plant the crop. Furthermore, this model also supports organic farming to reduce environmental impacts from using chemicals, such as synthetic fertilizers and pesticides, that are commonly used in conventional agriculture.

Materials and Methods

There were four methodological phases: data collection, model development, numerical experiments, and analysis and data interpretation. Fig. 1 shows a flowchart of this research methodology.

Data collection

The data required were the crop scheduling goals, demand and characteristics of the plants and plots. These three types of data were used in the optimization model developed.

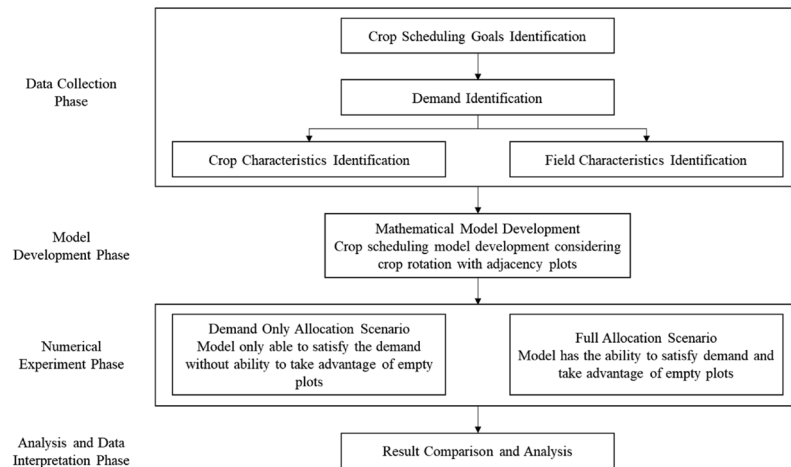


Fig. 1 Research methodology flowchart

The crop planning goals were determined based on observations on a sample farm in Central Java, Indonesia. The sample farm was run organically in accordance with the current research aim. The farmer owner provided information related to the organic crop production process. Crop rotation goals could be maximizing profit or satisfying demand. After the crop planning goal was defined, it was converted into model parameters based on demand, plot characteristics and plant characteristics.

Data collection was undertaken regarding buyer demand that was used as the formal target in the planning model. The data consisted of information on the type of crop and when and how much of the crop was required. This demand data consisted of all farm customers in a 40 week period for each of the eight types of crop: romaine (R), lettuce (LE), cucumber (CU), luffa (LU), potato (P), cowpea (CP) and groundnut (GN).

This study also utilized plot and crop characteristic data. Plots represented square subareas of the total planted area (Figs. 2 and 3 for planting and plot layouts, respectively). Plot characteristics were used to describe adjacency between plots and the production capacity from each plot. The data included the model of the plot, the location of each plot and the size of the plot sections. The land in the model consisted of several plots adjacent to others: Plot 1.1 was adjacent to Plot 1.2, Plot 1.3 was adjacent to Plot 1.4, Plot 2.1 was adjacent to Plot 2.2 and Plot 2.3 was adjacent to Plot 2.4.

Crop characteristics consisted of information regarding crop family, planting period, cost structure, revenue model and nutrient requirements. Crop characteristics data were obtained from sample farms and from other research (dos Santo et al., 2011). Data related to crop families were used in adjacency plots, where crops from the same family should not be planted in the same location in the same period to avoid pest attacks.

For example, romaine and lettuce come from the Asteraceae family, so these plants should not be planted close together in the same period.

Model development

The proposed model focused on crop planning based on organic farming system rules represented by adjacency plot constraints and nutrient cycling levels developed by dos Santo et al. (2011) and Filho et al. (2014). The crop planning model determined what type of crop to plant, when and where, as well as how much production was required to match the required demand.

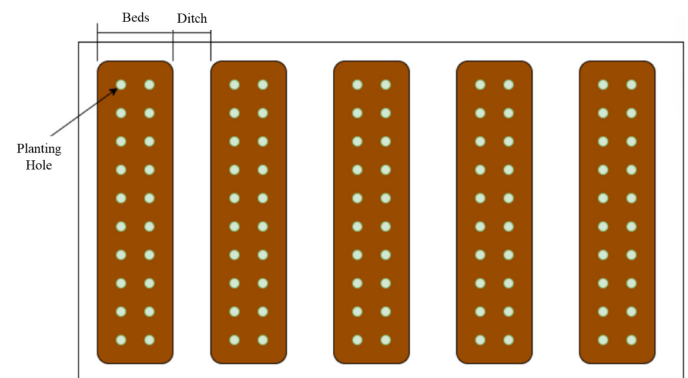


Fig. 2 Diagram of planting layout in plots

Plot 1.1	Plot 2.1	Plot 3.1	Plot 4.1	Plot 5.1
Plot 1.2	Plot 2.2	Plot 3.2	Plot 4.2	Plot 5.2
Plot 1.3	Plot 2.3	Plot 3.3	Plot 4.3	Plot 5.3
Plot 1.4	Plot 2.4	Plot 3.4	Plot 4.4	Plot 5.4

Fig. 3 Plot layout

MILP was applied to describe land allocation using binary decision variables. The researchers had to first develop the MILP model using references from several related studies. MILP is often used to build system optimization models since it provides a flexible and powerful method for solving complex problems (Kantor et al., 2020). The current study used MILP since not all the decision variables were integers. The results of the MILP approach describe land allocation using a binary decision variable.

The model was developed to satisfy the contract demand by assuring production revenue. Contract demand is an order from a customer that has been received several weeks or months ago. If the farmer does not fulfil the contract demand, the farmer must pay a penalty fee. The applied organic farming system considered several rules: 1) crop rotation—crops from the same botanical family cannot be planted in sequence; (2) adjacency plots—crop from the same botanical family cannot be planted in adjacent locations; (3) nutrient cycling level—soil nutrient must be at the optimum level; (4) fallow period—must be applied to all for the recovery of nutrient levels in the soil naturally.

Mathematical model

Based on the review of models by dos Santo et al. (2011) and Filho et al. (2014), the chosen mathematical model utilized MILP with a binary value as the decision variable. The mathematical model consisted of the objective function (the goal of the model) and the constraints (limitations binding the model to find the optimum value). The model objective was to maximize the profit by seeking the best what, when and where options for crop establishment and harvest following economic limitations.

The following parameters were used in the equations used in the model.

$Nbuy_{jkl}$	= amount of additional organic fertilizer;
i	: type of crop ($i \in I$)
j	: period
k	: block of land
l	: plot of land ($l \in L$)
$NUptake_i$	: amount of nutrient uptake of crop i
N_{jkl}	: amount of nutrient in period j on block k plot l
NF_{jkl}	: nutrient from fallow period in period j on block k plot l
W_{ijkl}	: amount of crop i produced in period j on block k plot l (kg)
D_{ij}	: demand of crop i in period j
$Prod_{ij}$	: total of crop i produced in period j
$Surplus_{ij}$	: total of crop i surplus in period j
SP_i	: selling price of crop i

t_i	: crop cycle time for crop i ,
$FCost$	: fixed cost
$VCost_i$	: variable cost of planting crop i
$F(P)$	: set of crops from crop family $p = (p = 1, \dots, Nf)$
S_k	set of adjacent plots to plot k ,
$Cashflow_j$	: total of crop i surplus in period
$MaxY_i$	: maximum yield of crop i
$Coeff_i$	: curvature coefficient crop i
$Gain_i$	: gain in yield of crop i based on the nutrient application

Decision variable

The decision variable in the MILP model was described as:

$$X_{ijkl} \begin{cases} 1, & \text{if crop } i \text{ planted in period } j \text{ on block } k \text{ plot } l \\ 0, & \text{else} \end{cases}$$

Objective function

The decision variable in the MILP model was described using Equation 1:

$$\text{Max} \sum_j \sum_i Prod_{ij} \times SP_i - \left(FC + \sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L x_{ijkl} \times (VC_i) + \sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{l=1}^L NAdd_{ijkl} \times NC \right) \quad (1)$$

The objective function of the model was profit maximization as stated in Equation 1. There were three main cost components: fixed, variable and additional nutrient. Fixed costs consisted of land rent, machine depreciation, labor costs, greenhouse maintenance and overheads. Labor costs consisted of supervisors and operational staff paid a fixed salary, equivalent to about USD 127.27 and USD 63.64, respectively, for each period. Variable costs consisted of seed purchase, land preparation, and harvesting.

Crop planning constraint

There were several constraints. Since each plot can be planted with all types of crops, in order to imitate actual conditions, it was necessary to create a limitation that only a single crop could be planted at a specific location and time, as stated in Equation 2.

$$\sum_{i=1}^n \sum_{r=0}^{t_i-1} x_{i(j-r)k} \leq 1, \quad j = 1, \dots, M, \quad k = 1, \dots, L \quad (2)$$

If a single crop has been assigned to a specified location and period, then no other crop can be planted in the same location until the first crop has been harvested. For example, crop A is

planted in period n on plot 1 and has a planting period of x . Therefore, no crop can be assigned until period $n+x$.

Crop rotation constraint prevented planting crops from the same botanical family being planted in sequence. For example, if crops B and A are in the same botanical family and if crop A is planted in period n , then crop A and crop B are not allowed to be planted after crop A is harvested. This constraint is presented in Equation 3:

$$\sum_{i \in F(p)} \sum_{r=0}^{t_i} x_{i(j-r)k} \leq 1, \quad p = 1, \dots, N_f, \quad j = 1, \dots, M, \quad k = 1, \dots, L \quad (3)$$

Adjacency plot constraint

The adjacency plot constraint prevented allocating crops from the same family in adjacent plots, as represented by Equation 4.

$$\sum_{i \in F_p} \sum_{r=0}^{t_i} [x_{i(j-r)u} + x_{i(j-r)v}] \leq 1, \quad p = 1, \dots, N_f, \quad j = 1, \dots, M, \quad (u, v) \in S_k \quad (4)$$

Demand constraint

As this model follows the pull supply chain concept, production must satisfy the demand. Equations 5 and 6 are based on the concept of Cerrato and Blackmer (1990). Equation 7 ensures production fulfils demand. In this model, the demand is individually defined for each crop in each period.

$$w_{ijkl} = \sum_i (MaxY_i - (Gain_i \times Coeff_i^{\sum AddN_{(j-t_1)kl}})) \quad (5)$$

$$\sum_{i=1} \sum_{j=1} \sum_{k=1} \sum_{l=1} (w_{ijkl} \times x_{ijkl}) = Prod_{ij} \quad (6)$$

$$Prod_{ij} \geq D_{ij} \quad (7)$$

Nutrient cycling constraint

Nutrient cycling follows the concept of cash flow. The level of each period depends on how much nutrient has been removed from the plant, and how much additional nutrient is needed, as shown in Equation 8:

$$N_{jkl} = N_{(j-1)kl} + NBuy_{jkl} + N_{jkl} + NF_{jkl} \quad (8)$$

The nutrient removed from the planted crops is continuous until the crop is harvested. The amount of removed nutrient from each crop was assumed to be the same in each period, with the average value of nutrients needed by the crop shown in Equation 9:

$$N_{jkl} = \sum_j \sum_k \sum_l x_{ijkl} \times NPK_i \quad (9)$$

In this model, the nutrient level was defined as the percentage of nutrients available in the land. The level of nutrients is approximately 30–100 kg to achieve the optimal product yield. Therefore, the nutrient was bounded, as shown in Equation 10:

$$Nmin \leq NLand_{jkl} \leq Nmax \quad (10)$$

Financial constraint

In the proposed model, cash flow must be positive. Equation 11 ensures that the cash flow is maintained based on input from revenue and output from fixed, crop variable and additional nutrient costs. The cash in each period was dependent on the amount from the previous period.

$$\begin{aligned} Cashflow_j = & Cashflow_{j-1} + \left(\sum_i Prod_{ij} \times SP_i \right) \\ & - \left(FC + \left(\sum_j x_{ijkl} \times (VC_i) \right) + \left(\sum_{j=1} NAdd_{jkl} \times NC \right) \right) \end{aligned} \quad (11)$$

Binary constraint

In the proposed model, the objective function of x_{ijkl} was represented by a binary value, as stated in Equation 12:

$$x_{ijkl} \in \{0,1\}, \quad i = 1, \dots, n, \quad j \in 1 \dots R, \quad k = 1, \dots, L \quad (12)$$

Integer constraint

In the proposed model, the objective function of $Nbuy_{jkl}$ was represented as an integer value, as stated in Equation 13:

$$Nbuy_{jkl} \in \{\text{integer}\} \quad j \in 1 \dots R, \quad k = 1, \dots, L \quad (13)$$

Numerical experiment

In this phase, the model was tested in a numerical experiment using several scenarios to capture the behaviour of the model. As the model follows the pull supply chain concept (demand-driven), there are two main scenarios run in this model. The first was the demand-only allocation scenario, in which the model was only able to satisfy the demand without taking advantage of empty plots. In this scenario, farmers could not sell crops excess to demands other than according to contracted demand. This scenario showed the behaviour of the model in satisfying the objectives to maximize profit and demand. Second, the full allocation scenario involved the model satisfying the demand and taking advantage of empty plots. This scenario captured the

behaviour of the model by utilizing empty plots that were cultivated to gain more revenue than that generated from only satisfying the demand. The data used in this numerical experiment were obtained from previous research and the sample farm.

Model validation

The model was tested using the initial parameters for reference to validate the model. The model parameters used the dataset demand-type 2 as the basis. Two scenarios of the model were run: the demand-only scenario and a full allocation scenario. The model was executed using the Microsoft Excel software (Microsoft Corp.; Redmond, WA, USA) with the OPENSOLVER add-in.

Results and Discussion

Model parameter calculation

The crop planning model with the pull supply chain concept used actual demand data for 40 weeks based on the contract with the buyer. Six crops were produced: romaine, lettuce, cucumber, potato, cowpea and groundnut (Table 1). Adjacency plot constraints were applied for romaine and lettuce and for cowpea and groundnut. Table 2 shows the demand data used.

Table 1 Crop information for model parameter

Crop	Family	Family category	Planting period (week)
Romaine	Asteraceae	1	4
Lettuce	Asteraceae	1	4
Cucumber	Cucurbitaceae	2	7
Potato	Solanaceae	3	11
Cowpea	Fabaceae	4	7
Groundnut	Fabaceae	4	7

Table 2 Model parameter demand in each period

No	Demand (kg)									
	Romaine		Lettuce		Cucumber		Potato		Cowpea	
1	Period 4	: 850	Period 10	: 370	Period 15	: 2000	Period 14	: 800	Period 8	: 3000
2	Period 14	: 820	Period 19	: 750	Period 18	: 2000	Period 19	: 800	Period 18	: 1400
3	Period 24	: 820	Period 30	: 750	Period 20	: 2000	Period 21	: 800	Period 26	: 2100
4	Period 35	: 800	Period 40	: 750	Period 26	: 2000	Period 29	: 800	Period 36	: 3000
5					Period 29	: 2100	Period 32	: 800		
6					Period 39	: 2000	Period 33	: 2400		
7					Period 40	: 1000	Period 39	: 1600		

Demand-only allocation scenario

The demand-only scenario create crop plan for an organic farming system by setting the model objective function to fulfil demand based on considering adjacency plot limitations, crop rotations and maintaining nutrients at optimum levels, as shown in Equation 14:

$$\text{Min} \sum_i \sum_j \text{Surplus}_{ij} \quad (14)$$

This objective function drove the model to address on-demand fulfillment, reflecting the condition of a single demand only, with no assurance to sell products beyond the predefined demand. Demand was set as a hard constraint. Otherwise, it would be unfeasible.

Fig. 4, Fig. 5, Tables 3, and Table 4 show the results of the demand-only allocation scenario with Demand Type 2. Furthermore, Fig. 3 shows the schedule for crop planting for 40 weeks for each plot and crop. This schedule was a model output for the first scenario. The value of the objective function was 2,748 kg of total surplus crops. Since the model's objective function was to minimize the surplus amount of the crop, planting a new plot was irrelevant.

The demand fulfilment rate was 107% or 7% of surplus crops. This was most likely since the production was based on plot bulking, because if a plot has been allocated, the land was assumed to be fully allocated to produce crops. The additional nutrient was required to fulfil demand requirements, such as for lettuce in period 4.

Based on the results, this scenario had a profit of USD 1,027.20, based on the margin between the revenues and costs incurred in the 40 periods of the planning horizon. The return on investment (ROI) was 8%, representing the total capital rate of return from this crop planning from investing USD 12,727.18 in capital. However, this scenario involved only 63% of plot allocation, which could have restricted the profit and ROI. The impact of limiting production to only fulfil the demand, resulting in empty plots was 37%.

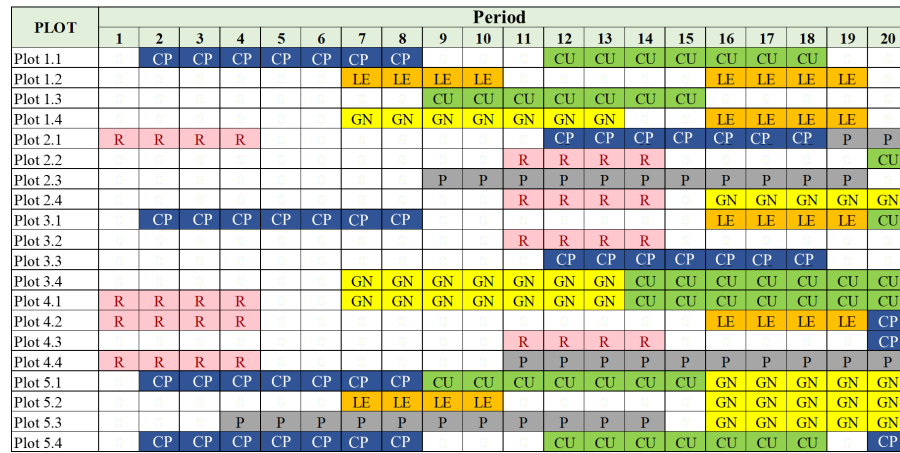


Fig. 4 Gantt chart of model parameters for demand-only allocation scenario, where CP = Cowpea; CU = Cucumber; R = Romaine; P = Potato; LE = Lettuce; GN = Ground nut

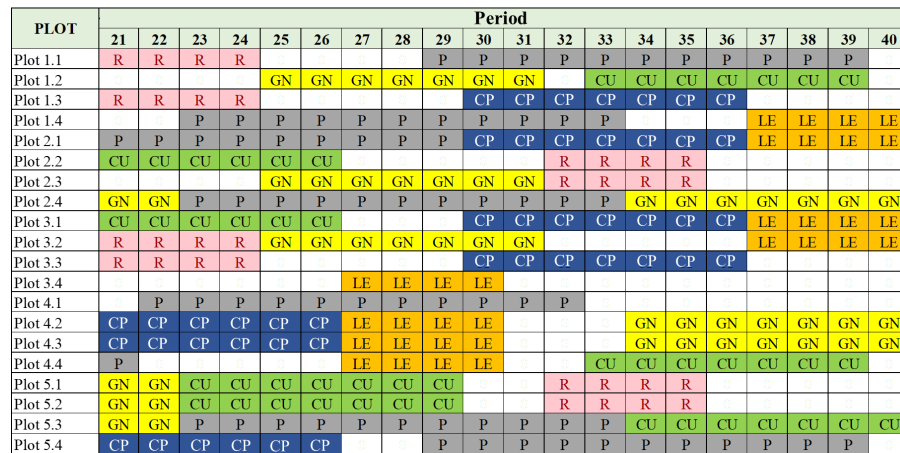


Fig. 5 Gantt chart of model parameters for demand-only allocation scenario, where CP = Cowpea; CU = Cucumber; R = Romaine; P = Potato; LE = Lettuce; GN = Ground nut (continued)

Table 3 Summary of demand-only allocation scenario, Demand Type 2

Parameter	Value
Plot utilization	63%
Demand fulfillment rate	107%
Additional nutrient needed (kg/planting period)	460
Additional fertilizer needed (kg/planting period)	9.200

Table 4 Financial summary for demand-only allocation

Cost component	Value
Revenue	USD 40,546.61
Fixed cost	USD 10,238.31
Crop variable cost	USD 26,353.85
Additional nutrient cost	USD 2,927.25
Profit	USD 1,027.20
Return on Investment	8%

Note: actual costs in Indonesian rupiah and converted at USD 1 = IDR 15,714.40.

Full allocation scenario

In this scenario, the model maximized land allocation to achieve the main objective of maximizing profit. The full allocation scenario relaxed the constraints to utilize empty plots to gain profit additional to that the contract demand. The demand used for this scenario was also based on Demand Type 2.

Fig. 6, Fig. 7, Tables 5 and 6 show the results of the full allocation scenario based on Demand Type 2. Fig. 5 shows the schedule for crop planting for 40 weeks for each plot and crop. This scenario pushed plot utilization to the maximum level, resulting in 89% plot utilization. The demand fulfillment rate was 164%, indicating that the model added an additional 64% to the total production in addition to contracted demand. Luffa was used in this model to fill the gap, with cowpea as the second most profitable crop.

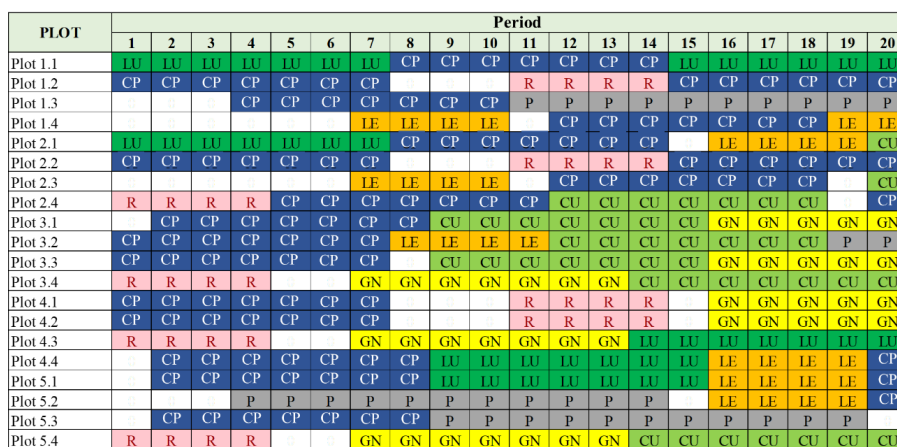


Fig. 6 Gantt chart of model parameters for full allocation scenario, where LU = Luffa; CP = Cowpea; CU = Cucumber; R = Romaine; P = Potato; LE = Lettuce; GN = Ground nut

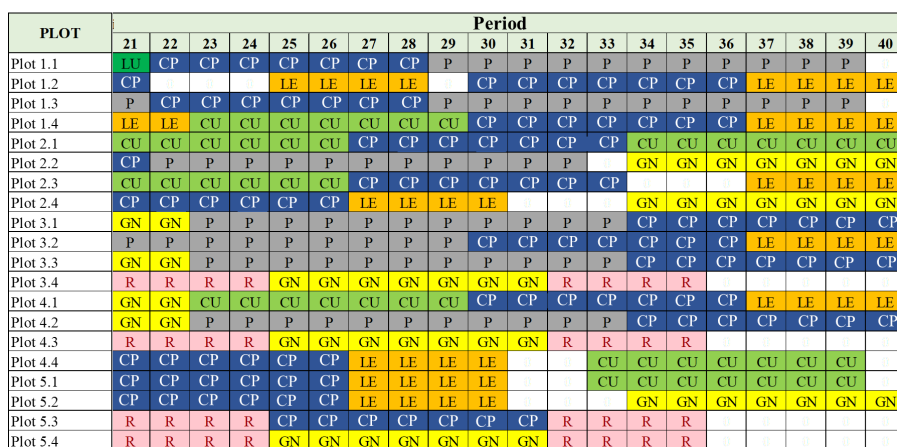


Fig. 7 Gantt chart of model parameters for full allocation scenario, where LU = Luffa; CP = Cowpea; CU = Cucumber; R = Romaine; P = Potato; LE = Lettuce; GN = Ground nut (continued)

Table 5 Summary of full allocation scenario

Parameter	Value
Plot utilization	89%
Demand fulfillment rate	164%
Additional nutrient needed (kg/planting period)	617
Additional fertilizer needed (kg/planting period)	12.340

Table 6 Financial summary for full allocation scenario

Cost component	Value
Revenue	USD 60,612.99
Fixed cost	USD 10,238.31
Crop variable cost	USD 37,367.13
Additional nutrient cost	USD 3,926.34
Profit	USD 9,081.28
Return on Investment	71%

Actual costs in Indonesian rupiah and converted at USD 1 = IDR 15,714.40.

The profit from this second scenario was USD 9,081.28 based on the margin between the revenues and costs incurred in the 40 periods of the planning horizon. Maximizing land utilization increased the profit mainly because the fixed cost was cheaper per product unit along with the revenue increase. The profit from the first demand-only allocation scenario was less (USD 1,027.20) because the fixed costs were greater for the reduced revenue from the smaller area under crops. With the utilization of empty plots, the ROI in the second model was 71% from investing USD 12,727.18 in capital.

Numerical experiment

Each scenario acts differently to achieve its objective. The demand-only scenario focused on minimizing the crop surplus

to only satisfy the demand, while the full allocation scenario had an additional goal to maximize profit, which was related to maximizing plot utilization.

Profit refers to the total profit for the crops produced and the types of crops planted. Table 7 compares the numerical experiments. For the demand-only scenario, the Demand Type 2 only generated a profit of USD 1,027.20 compared to numerical experiment 1 with USD 2,875.05 because the demand for the model parameter considered several types of crop with different crop benefits.

Numerical experiment 3 produced the maximum profit the farm can receive. Compared to the model parameter full allocation with Demand Type 2, there were several gaps that could not be utilized because of the demand pattern because: 1) the remaining gap was less than the shortest crop planting period; or 2) the organic planting system constraints came into effect. These reasons also applied to plot utilization. While numerical experiment 3 provided 96% plot utilization, the models of full allocation in the model parameter and numerical experiment 1 were limited to 89% and 88%, respectively, due to the demand pattern.

The consideration of the type of crop choice to be planted in the empty plot for the whole allocation scenario was based on the highest profit/plot/planting period. It seemed that the highest profit was achieved without considering the planting period. However, since the planting period differs for each crop, the crop values differ, as shown in Table 8. For example, in the proposed model numerical experiment, potato provides

a higher profit compared to lettuce. However, potato requires 11 periods. In contrast, lettuce only required four periods. Therefore, based on per planting period, lettuce is more profitable than potato. In addition, two crops of lettuce utilizes the same period as only one crop of potato.

An organic farming system focuses on providing soil organic matter in safe and sustainable ways to reduce excessive disturbance to the soil (Food and Agriculture Organization of the United Nations, 2021). The objective of an organic farming systems is to create nutrient cycling to improve soil quality by using natural resources (Stockdale et al., 2001). Maintaining soil quality maintains the environmental quality of the farm and assists production sustainability (Ladha et al., 2005).

The numerical experiment considered implementing the organic farming system based on crop rotation, adjacency plots and nutrient cycling. Crop rotation generates healthy soil and has a pest control function (Mohler and Johnson, 2009), while 53% of farmers preferred the stable production planning concept to minimize crop changes over short periods (Reyer et al., 2013). Furthermore, those farmers preferred a mono-cropping system or long crop rotations. Adjacency plots would reduce risk of pest attacks which could be easily spread through water, soil and air (Tan and Nihan, 2012).

The developed model could be used as a decision-making tool for farmers or farm business entities in deciding on the crop type and when and where to plant to optimize the desired outcomes. The model tended to increase productivity rather than utilize another plot to satisfy the demand. This study applied

Table 7 Numerical experiment summary

Scenario	Demand	Feasibility	Profit (USD/planting period)	Crop surplus (kg/planting period)	Plot utilization
Model parameter	D2-demand only	Yes	1,027.20	2.748	63%
	D2-full allocation	Yes	9,081.22	25.566	89%
Numerical experiment 1	D1-demand only	Yes	2,875.05	3.059	55%
	D1-full allocation	Yes	15,852.88	37.099	88%
Numerical experiment 2	D3-demand only	No	-	-	-
	D3-full allocation	No	-	-	-
Numerical experiment 3	Full allocation	Yes	19,829.27	87.160	96%

Actual costs in Indonesian rupiah and converted at USD 1 = IDR 15,714.40.

Table 8 Crop benefit comparison ranked on profit per plot per planting period

Ranking	Crop	Profit/plot (USD)	Planting period	Profit/plot/planting period
1	Cowpea	446.41	7	67.77
2	Potato	434.00	11	39.45
3	Luffa	276.18	7	39.45
4	Lettuce	122.86	4	30.71
5	Romaine	116.03	4	29.01
6	Cucumber	188.68	7	26.95
7	Groundnut	138.15	7	19.74

Actual costs in Indonesian rupiah and converted at USD 1 = IDR 15,714.40.

the model to demand only with full allocation conditions. The experimental runs showed that the full allocation condition resulted in higher plot utilization with a profit difference of USD 12,977.83/planting period.

The proposed model does not consider environmental and weather factors; these should be investigated in future research. In addition, as the nutrient uptake in the proposed model was assumed to have the same value in each planting period, it would be beneficial to consider a dynamic approach for the nutrient uptake model. Furthermore, the proposed model was set to satisfy demand; thus any unsatisfied demand would be captured as an unfeasible solution. It would be beneficial to consider a model that could handle both a surplus and shortfall in production. Finally, the proposed model used profit as a measure of productivity. Future research could consider other components to measure productivity.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgement

The authors gratefully acknowledge financial support from the Institut Teknologi Sepuluh Nopember for this work, under project scheme of the Publication Writing and IPR Incentive Program (PPHKI) 2023.

References

- Assefa, S., Tadesse, S. 2019. The principal role of organic fertilizer on soil properties and agricultural productivity – A review. *Agricultural Research and Technology* 22: 556192.
- Cerrato, M.E., Blackmer, A.M. 1990. Comparison of models for describing corn yield response to nitrogen fertilizer. *Agron. J.* 82: 138–143. doi.org/10.2134/agronj1990.00021962008200010030x
- Despoudi, S., Papaioannou, G., Saridakis, G., Dani, S. 2018. Does collaboration pay in agricultural supply chain? An empirical approach. *Int. J. Prod. Res.* 56: 4396–4417. doi.org/10.1080/00207543.2018.1440654
- Director General of Horticulture. 2019. Strategic Plan of the Director General of Horticulture for 2020–2024. Ministry of Agriculture of The Republic of Indonesia. Jakarta, Indonesia. [in Indonesian]
- dos Santo, L.M., Michelin, P., Arenales, M.N., Santos, R.H. 2011. Crop rotation scheduling with adjacency constraints. *Ann. Oper. Res.* 190: 165–180. doi: 10.1007/s10479-008-0478-z
- Food and Agriculture Organization of the United Nations. 2021. The role of conservation agriculture in organic matter deposition and carbon sequestration. <https://www.fao.org/3/a0100e/a0100e0a.htm#:~:text=Conservation%20agriculture%20makes%20use%20of,provide%20organic%20matter%20and%20nutrients>, 24 May 2021.
- Fikry, I., Gheith, M., Eltawil, A. 2021. An integrated production-logistics-crop rotation planning model for sugar beet supply chains. *Comput. Ind. Eng.* 157: 107300. doi.org/10.1016/j.cie.2021.107300
- Filho, A.A., Florention, H.d., Pato, M.V. 2014. Metaheuristics for a crop rotation problem. *Int. J. Metaheuristics* 3: 199–222. doi.org/10.1504/IJMHEUR.2014.065169
- Jahel, C., Augusseau, X., Seen, D.L. 2018. Modelling cropping plan strategies: What decision margin for farmers in Burkina Faso? *Agric. Syst.* 167: 17–33. doi.org/10.1016/j.agsy.2018.08.004
- Kantor, I., Robineau, J.L., Bütün, H., Marechal, F. 2020. A mixed-integer linear programming formulation for optimizing multi-scale material and energy integration. *Front. Energy Res.* 8: 49. doi.org/10.3389/fenrg.2020.00049
- Karlen, D.L., Sharpley, A.N. 1994. Management strategies for sustainable soil fertility. In: Hatfield, J.L., Karlen, D.L. (Eds.). *Sustainable Agricultural Systems*. CRC Press. Florida, FL, USA, pp. 47–108.
- Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J., van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Adv. Agron.* 87: 85–156. doi.org/10.1016/S0065-2113(05)87003-8
- Makarim, A.I. 2015. The Basic Model of the Annual Cropping Pattern of Food Crops. Laporan Hasil Penelitian. Puslitbang Tan aman Pangan. Badan Litbang Pertanian. Indonesia. [in Indonesian]
- Mohler, C.L., Johnson, S.E. 2009. *Crop Rotation on Organic Farms: A Planning Manual*. Plant and Life Sciences Publishing. New York, NY, USA.
- Prihastuti, P. 2011. Structure of soil microbial community and its implications in realizing a sustainable agricultural system. *El-Hayah Jurnal Biologi* 1: 174–181. [in Indonesian]
- Randall, M., Montgomery, J., Lewis, A. 2022. Robust temporal optimisation for a crop planning problem under climate change uncertainty. *Oper. Res. Perspect.* 9: 100219. doi.org/10.1016/j.orp.2021.100219
- Reyer, C.P., Leuzinger, S., Rammig, A., et al. 2013. A plant's perspective of extremes: Terrestrial plant responses to changing climatic variability. *Glob. Change Biol.* 19: 75–89. doi.org/10.1111/gcb.12023
- Stockdale, E.A., Lampkin, N.H., Hovi, M., et al. 2001. Agronomic and environmental implications of organic farming systems. *Adv. Agron.* 70: 261–327. doi.org/10.1016/S0065-2113(01)70007-7
- Tan, B., Nihan, Ç. 2012. Agricultural planning of annual plants under demand, maturation, harvest, and yield risk. *Eur. J. Oper. Res.* 220: 539–549. doi.org/10.1016/j.ejor.2012.02.005
- Triberti, L., Nastri, A., Baldoni, G. 2016. Long-term effects of crop rotation, manure and mineral fertilisation on carbon sequestration and soil fertility. *Eur. J. Agron.* 74: 47–55. doi.org/10.1016/j.eja.2015.11.024
- Urbano, T., Moro, S. 1992. *Agricultural Systems with Crop Rotations and Alternatives*. Ediciones Mundi-Prensa. Madrid, Spain.
- Villa, G., Adenso-Diaz, B., Lozano, S. 2019. An analysis of geographic and product diversification in crop planning strategy. *Agric. Syst.* 174: 117–124. doi.org/10.1016/j.agsy.2019.05.006
- Zhang, C., Engel, B.A., Guo, P., Zhang, F., Guo, S., Liu, X., Wang, Y. 2018. An inexact robust two-stage mixed-integer linear programming approach for crop area planning under uncertainty. *J. Clean. Prod.* 204: 489–500. doi.org/10.1016/j.jclepro.2018.09.005